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A STRATEGIC APPROACH FOR EXISTING BUILDINGS TO WITHSTAND CLIMATE CHANGE

T. Valdbjørn Rasmussen

Abstract

Buildings play a vital economic and social role in society and are vulnerable to climate change. This paper suggests a strategic approach for existing buildings to withstand climate change. It emphasises the most likely climate impacts, including the change in mean year values as well as the extent of maximum and minimum extremes, which are pointed out and set against a background of national and international agreements. Assumptions that form the basis for the scenarios are outlined and evaluated in a Danish context and similar evaluations can be drawn for other countries. As climate change progresses, the uncertainty of the scenarios leaves major challenges that will grow far more serious, if not addressed and taken into account in building design and into a strategy for the adaptation of existing buildings.

An outline of the actions needed for developing a broad strategic approach to the adaptation to climate change for buildings is given. The actions include four stages: a survey of the performance, the impact of climate change, the vulnerability of the existing building stock and climate adaptation needs. This leads to the identification of a risk-based strategic framework for adaptation to climate change based on the results of a vulnerability analysis. In addition, this paper describes some issues that must be addressed in case a strategic approach is not developed, as the building sector is continuously investing in measures to adapt to climate change.

Keywords: Climate Change, Impact, Effects, Strategy, Buildings.

INTRODUCTION

Climate change and measures to mitigate its effects are issues of high priority in industrial countries including Denmark. In spite of efforts to develop a broad strategic approach to climate change, adaptation of existing buildings does not appear to be a high priority.

In 2005, the Danish Government presented an action plan that aimed to promote significant results in the energy field. This action plan has already and will continue to have an impact on Danish energy-saving initiatives in the years to come (Ministry of Transport and Energy 2005). The action plan includes an outline of the Danish energy sector in the years leading up to 2025. One subject in the strategy is the climate policy related to the Kyoto Protocol (UN 1998), which was enforced on February 16, 2005. Industrialised countries signatory to the Protocol were obliged to limit their emissions of greenhouse gases between 2008 and 2012. As part of the internal obligations within the European Union (EU), Denmark was required to reduce its emissions by 21% compared with 1990 emissions (Olesen et al. 2004). Furthermore, the

draft action plan contains energy-saving initiatives prescribing that consumer energy consumption should be reduced by an average of 1% per annum from 2006 to 2012.

The effort of elaborating a new climate policy agreement failed at the Conference of the Parties (COP) meetings number 15 (COP15), 16 (COP16) and 17 (COP17), held in Copenhagen, Mexico City and Durban, in December 2009, 2010 and 2011, respectively. It was intended to succeed the Kyoto Protocol (UN 1998) by introducing obligations to limit emissions of greenhouse gases after 2012. At COP17 it was stated that from 2012 only the member states of the European Union will succeed the Kyoto Protocol including new Kyoto-obligations to limit emissions of greenhouse gases. However, the Parties agreed on the development of a new global climate agreement that must include all countries with the largest emissions of greenhouse gases. The new global climate agreement needs to be agreed on in 2015 and come into force in 2020. At COP 15, a Green Fund was agreed and at COP17 the fund was designed, with the purpose of aiding underdeveloped countries in meeting the challenges of climate change.

The European Union continues agreed independently on their climate visions (CEU 2009). The ambition was global and aimed to limit global warming to a maximum of 2°C and reduce 1990 emissions of greenhouse gases by a total of 80-95% in industrial countries by 2050. As a consequence, the Danish Commission on Climate Change Policy presented their ambitions in 2010. These ambitions outline Danish energy-saving initiatives, energy supply investments, energy distribution and a slow-down of climate change in the years leading up to 2050 (Danish Commission on Climate Change Policy 2009). Three main issues related to the built environment, outlined in the plan, are:

- (i) Changing the energy supply to be independent of fossil fuels by 2050. Today 80% of the energy demand in Denmark relies on fossil fuels like oil, coal and gas.
- (ii) Mitigating the effects of climate change by implementing a large reduction of the emissions of greenhouse gases. Emissions from a large number of agents needs to be included i.e. fossil fuels and carbon dioxide from i.e. farming, industrial processes, solvents, methane and nitrous oxide from plastics in waste and sewage along with industrial gases as hydro fluorocarbon gases, sulphur hexafluoride gases and perfluoro-compound gases.

- (iii) Adaptation of the built environment to the future climate.

In Danish society, buildings have a replacement value of approximately €1,600 to €1,850 billion. The value is determined in 2010 for the whole country based on built-up area (Statistics Denmark 2010) with a mean value of 2,400 €/m². The value of infrastructure such as roads, rails, bridges, embankments, harbours and sewers are not taken into account. The floor area of new buildings constructed each year makes up about 1% of the total floor area of buildings. It is crucial to preserve the value of the building stock, and it is therefore important to adapt the building stock to the challenges of the future climate.

As buildings play a vital economic and social role in society and are vulnerable to climate change an effort to preserve their satisfactory performance and value are needed. The paper suggests and outlines actions needed for developing a broad strategic approach for existing buildings to withstand climate change. As effects of climate change are a serious challenge for the design and upgrading of buildings, adaptation must include key requirements dictated by the effects of climate change, that for the time being are uncertain and evaluated differently in different countries.

Scenario	A2 ¹			B2 ²			EU2C ³		
Year	2006-2035	2036-2065	2071-2100	2006-2035	2036-2065	2071-2100	2006-2035	2036-2065	2071-2100
On land, change in:									
Annual average temperature [°C]	+0.6	+1.4	+3.1	+0.7	+1.4	+2.2	+0.7	+1.2	+1.4
Average winter temperature [°C]	+0.6	+1.4	+3.1	+0.7	+1.3	+2.1	+1.0	+1.7	+2.0
Average summer temperature [°C]	+0.5	+1.3	+2.8	+0.6	+1.3	+2.0	+0.7	+1.1	+1.3
Annual rainfall [%]	+2	+4	+9	+2	+5	+8	0	0	0
Winter rainfall [%]	+8	+19	+43	+6	+11	+18	0	0	+1
Summer rainfall [%]	-3	-7	-15	-2	-4	-7	-2	-3	-3
Maximum daily rainfall [%]	+4	+10	+21	+5	+12	+20	+11	+18	+22
At sea, change in:									
Average wind speed [%]	+1	+2	+4	+1	+1	+2	+1	+1	+1
Maximum wind speed [%]	+2	+5	+10	0	+1	+1	+1	+1	+1
Maximum sea level [m] (West Jutland)			+0.45-1.05						

Note: ¹Scenario A2 assumes a world with little global economic integration and a slow development and distribution of effective technological solutions that can reduce the emissions of greenhouse gases. Furthermore, it is assumed that population growth will continue to be high (Nakićenović et al. 2000, Danmarks Meteorologiske Institut 2010).

²Scenario B2 assumes, like scenario A2, a world with little global economic integration and a slow development and distribution of effective technological solutions that can reduce the emissions of greenhouse gases. Scenario B2 considers a situation with more reduced emissions of greenhouse gases than scenario A2 as a result of moderate population growth and more environmentally conscious consumers (Nakićenović et al. 2000, Danmarks Meteorologiske Institut 2010).

³Scenario EU2C assumes a world-wide implementation of a large reduction of the emissions of greenhouse gases. Industrial countries reduce their emissions of greenhouse gases by 80-95% by 2050 compared with 1990 emissions. Consequently global warming will be limited to a maximum of 2°C (Nakićenović et al. 2000, Danmarks Meteorologiske Institut 2010).

Table 1. Projected climate change based on A2, B2 and EU2C scenarios.

Indicator	Scenario			
	A2	B2	EU2C	P*
Number of days with frost (days/year with T_{min} under 0°C)	-44	-31	-26	73
Growth season's length (days in a row over 5°C)	55	39	22	224
Longest heat wave/year (days in a row, T_{max} more than 3°C over normal)	9	4	4	5
Hot summer nights (% days T_{min} over normal 90 percentile)	20	13	10	10
Number of days with ≥ 10 mm rainfall (days/year)	3	3	-1	03
Largest volume of 5-day rainfall/year (mm/5 days)	4	4	1	47
Average intensity of rainfall for days with more than 1 mm rainfall (mm/day)	0.3	0.3	0	4.7
Extreme rainfall (% rainfall over 95 percentile)	5	6	0	32

Note: * P denotes present events that are the mean values of the number of events measured in the period 1961-1990.

Table 2. Extreme climate events in the present-day climate and projected changes in climate scenarios.

CLIMATE IMPACTS

The adaptation needed in the built environment is closely related to the projected climate impacts. Available emission scenarios A2 and B2 (Nakićenović et al. 2000, DMI 2005), as well as EU2C (Danish Government 2008) were used as a basis for the Danish strategy for adapting to a changing climate (Danish Government 2008), as they are considered the most likely in Denmark. The scenarios describe the projected climate impacts in Denmark leading up to 2100 and are shown in Tables 1 and 2.

BUILDING PERFORMANCE REQUIREMENTS

Buildings are designed and constructed based on building requirements. Today building requirements are based on measured climate data and put into practice typically by performance-based building requirements. Buildings designed on the basis of these requirements will very likely be exposed to and threatened by climate impacts, in case these have not been taken into account in the building design. At present, climate impacts therefore pose a serious problem in relation to the design and upgrading of buildings.

The effects of climate change are only part of the demands that a building must meet. These demands include requirements to architecture, to the use of the building, including providing safety, with no danger of collapse, even during extreme storms or snowfalls. A building should be comfortable to live in, providing thermal comfort, regardless of weather conditions and good indoor air quality, as well as facilitating the use of surroundings when weather permits. In addition, buildings should be durable with moderate maintenance

costs. The most serious demands related to the loss of life or health, must utilise the highest safety levels so the effects of climate change can be neutralised. In some cases, it might prove to be much more expensive to upgrade a building after having finished the construction, than it would have been if the right standard had been part of the original design. However, upgrading a building to meet key climate impacts can be part of the original design and can be done at almost no extra costs at the time of construction. This is of the utmost importance for structures with the longest expected life time such as load-bearing foundations, walls and floor decks.

NEEDED STRATEGIC APPROACH

How buildings address threats or make use of opportunities presented by the projected climate impacts have enormous economic consequence. However, until the quality of input data determining reliable climate change scenarios has improved, full advantage of more advanced tools is not possible. This leaves the uncertainty of the relevant climate scenarios as being one of the key issues.

A strategy for adaptation needs to be implemented, as climate impacts will dictate future building requirements. The need for adaptation measures are closely related to the exact location of the building, building design and the local effects of climate change.

A strategic approach to climate change adaptation needs to be developed to ensure the vital economic and social role of buildings in society. The strategic approach must include the following tasks:

1. A performance model
2. An impact model
3. Vulnerability analysis
4. An adaptation strategy

The elements of a strategic approach that address the threats or make use of opportunities, presented by the projected climate impacts are given in Figure 1 and these should be included in design and continuous upgrading and maintenance of buildings. The lack of a strategic approach will result in stand-alone initiatives and ad-hoc upgrading of buildings as climate change progresses.

Figure 1. Elements in a strategic approach that include addressing effects of climate change and needs of adaptation. Absence of a strategic

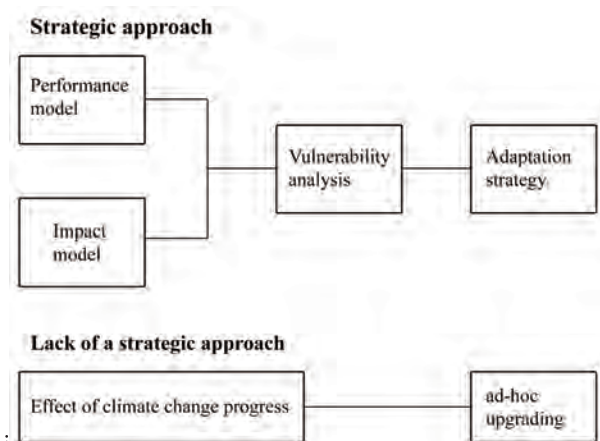


Figure 1. Strategic approach

approach will result in ad-hoc upgrading of buildings as the effects of climate change emerges.

ELEMENTS OF THE STRATEGIC APPROACH

The tasks 1), 2), 3) and 4) are further described in the following sections.

A performance model

Since buildings have a long life and since existing buildings might in future develop performance problems in meeting requirements related to climate change (Nielsen 2006, Meløysund et al. 2006), it is important to develop a performance model for the existing building stock that covers both new and old buildings. Development of a building stock typology model is necessary. The model could be developed as a basis for defining and managing risk related to the building performance.

The model could build on a typological model of the building stock based on four categories consisting of the design type (detached housing; multi-storey housing; administration, education), age and construction (external walls; roof; ground floor/foundations; internal walls/floors). Such information can be found in already published research i.e. scotch information concerning the Danish building stock is given in (Wittchen 2009). The typologies could be followed up by a set of performance criteria (Backer 2008). A criterion, e.g. structural safety could be correlated to climate parameters such as wind speed, weight of snow or soil moisture, describing necessary performance-based building requirements.

An impact model

There is a need to define climate impacts relevant

for the building sector and based on the performance model (5.1). It will be necessary to evaluate currently known climatic parameters and define new climatic parameters such as for temperature, precipitation, wind speed, atmospheric humidity, solar radiation and soil moisture. The parameters must also include mean monthly and seasonal values as well as the frequency and extent of maximum and minimum extremes. It is important to set up a probabilistic model of the impact of climate change on the built environment.

Many of these data can be retrieved from archives containing the outputs of the regional climate model at 12-50 km resolution from the Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects (PRUDENCE) (DMI 2005, Christensen et al. 2007) and the Climate Change and its Impacts at Seasonal, Decadal and Centennial Timescales (ENSEMBLES) (van der Linden and Mitchell 2009) projects. The available emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES), (Nakićenović et al. 2000), as well as the EU2C scenario (Danish Government 2008) are used and described in section 2 Climate Impacts.

Lacking data required by the building sector need to be assumed as well. For assumed and found data, it is seen that there can be considerable uncertainty regarding the accuracy of the predictions. It will therefore be necessary to take account of these elements of risk by developing a model for climate impacts that span the predicted ranges of error.

Vulnerability analysis

On the basis of the performance model (section 5.1) and the impact model (section 5.2), it is possible to develop a method to analyse where future climate impacts causes weaknesses in building performance. For each performance requirement and design criteria defined in the performance model (section 5.1), it is necessary to define relevant calculation methods that can be used in relation to the climate scenario data sets developed in the impact model (section 5.2). This analysis will then be able to be carried out for each of the building types and ages defined in the performance model (section 5.1). Design criteria could i.e. cover structural safety, indoor comfort and energy consumption with climatic parameters such as wind speed/weight of snow/soil moisture, outdoor temperature/absolute humidity and outdoor temperature evaluated in

relation to calculation methods outlined in ISO (2007), DS 474:1995 (1995) and ISO (2008).

The models should be tested on representative buildings that should be followed up by on-site investigations related to the design criteria.

An adaptation strategy

The results of the vulnerability analysis (section 5.3) are expected to show, where performance vulnerability exists in relation to selected climate scenarios. On this basis, a risk-based strategic framework for climate adaptation for the building stock can be developed. This cross-disciplinary framework can include assessment models, monitoring technologies, and specific design solutions. This will lead to a method to describe the risks associated with adaptation to climate change based on climate impacts in relation to building performance vulnerability.

From these analyses, concrete adaptation solutions can be described according to the typological model of the building stock suggested to be the most suitable for each specific case. Suggestions can even be levelled according to the need of a low-, medium- or high-risk adaptation strategy ranging from the need of changes in building regulations and design approach to monitor changes of the certainty of climate change impacts.

DISCUSSION

Buildings play a vital economic and social role in most industrialised countries. In Danish society, it is estimated that buildings have a replacement value of €1,600 to €1,850 billion. The consequences that climate impacts may have on the existing built environment are not known, as climate impacts and hence the vulnerability of the existing building stock has yet to be investigated. This leaves society with major challenges that, if not addressed and taken into account, will grow far more serious as climate change progresses. The need for a strategic approach becomes even more urgent. Until a strategic approach has been launched, initiatives to challenge the climate impacts will be ad-hoc and stand-alone initiatives.

Many resources have been spent on defining data relevant for the building sector regarding the impact of climate change, and ever more data are needed as assumptions change over time. Assumptions are closely related to the successful mitigation of climate impacts. The impact of climate change on the built environment is unknown and

there are inevitably degrees of uncertainty associated with individual parameters such as temperature, precipitation, wind speed, relative humidity, solar radiation or soil moisture. In addition to the scenarios describing projected climate impacts; most countries in the world, including Denmark, have already witnessed extreme single events. Single events have been more intense than predicted and include extreme rainfall, heavier cloudburst, more frequent and longer periods of drought as well as increased winter rainfall. In Denmark data clearly show a rise in precipitation in the period from 1874 to 2010 (Drews et al. 2011).

Observations, from the last 100 years, show changes in the geographic pattern of precipitation globally. The connection between a warmer climate and heavier rainfall is confirmed by several studies. Some studies even estimate that the change in the total amount, seasonal variations and the intensity of rainfall estimated by the Intergovernmental Panel on Climate Change (Solomon et al. 2007) is underestimated both for the tropics and for Europe (Allan and Soden 2008, Lenderink and van Meijgaard 2008).

Without a strategic approach, building owners are presently uncertain which climate impacts are necessary to address and which scenarios have the most credibility. Existing buildings and buildings constructed today should be able to withstand climate impacts until 2100, as the main structures of buildings are expected to last for at least 100 years. The challenge of contemporary building requirements is that they should take account climate impacts for a period corresponding to the service life of individual building components. Climate impacts therefore pose a serious problem in relation to the design and upgrading of buildings. Besides threats from extreme rainfall and heavier cloudburst, which in most countries are considered the most urgent threats the threat of increased wind loads is also an extremely important threat which should be included in building design.

Scenario A2 in table 1 foresees an increased maximum wind load at sea of about 20% in year 2100, as the wind load depends on the square of the wind speed. Wind load is critical for most buildings and a threat that must be dealt with. A heavier wind load calls for stronger constructions. Compared with the safety margin of load-bearing structures in buildings, a 20% increase in the wind load is not critical. However, in 1999 a heavy storm in Denmark reached today's design wind standard and cost insurance companies sums that equalled

about 10% of the yearly investment in buildings in Denmark (Nielsen 2006). In addition, it was found that the damaged buildings had strengths of about half of what is required according to the building requirements (Munch-Andersen and Buhelt 2000). Therefore, a 20% increase of the wind load as a result of a 10% increase of extreme wind speed is supposed to result in a situation for which adaptation measures must be developed, both for existing buildings and for buildings that are to be designed for climate impacts. Such adaptation measures are expensive, but far less expensive than rebuilding damaged buildings after a storm worse than the Danish storm in 1999.

Another important climate impact is the possible threat posed by a more humid and warmer climate. This would challenge the building design that provides humans with thermal comfort, good indoor air quality, and durable constructions. Such challenges are unlikely to be met at moderate maintenance costs.

Data describing climate impacts for the different scenarios also contain data for some of the parameters needed for the design of buildings. Unfortunately, the data for the various scenarios omit statistical information about the different effects. However, that is the nature of scenarios, since they prescribe a point perspective rather than an interval at a specified level of certainty. This means that more sophisticated tools for risk analysis cannot be applied (Willows and Connell 2003). Circumstances demand a continued need for a strategic approach to climate impacts and adaptation for existing buildings and building requirements.

CONCLUSION

Lack of international agreements on the reduction of the emissions of greenhouse gases makes it difficult to expect anything but an economically regulated use of available fossil fuels such as oil, coal and gas globally. Due to the shortage of available fossil fuels together with an increasing demand and higher production costs, the same economic conditions will drive policy for energy use and the development of new and other energy-supply sources. However, the economically regulated use of fossil fuels and hence the emissions of greenhouse gases will lead to climate impacts that are very difficult to forecast and leave threats as well as opportunities for the design of buildings unknown. Therefore, it is unknown whether or not buildings constructed

today will be able to withstand the effects of climate change in 2100, as the main structures of buildings are expected to last for at least 100 years.

As climate change progresses, the effects of climate change will change the building requirements. However, as the impact of climate change is unknown, it is very difficult to forecast the necessary building requirements. This will leave investments that are necessary for the preservation of the value of the building stock as ad-hoc and stand-alone investments, as future climate impacts emerge. Losing the opportunity to upgrade a building to meet key climate impacts as part of the maintenance which increases the costs of necessary measures. Therefore, the uncertainty of the scenarios leaves major challenges that, if not addressed and taken into account in building design, will grow far more serious as climate change progresses.

A continuous strategic approach to climate change and adaptation needed to ensure the vital economic and social role of buildings in society grows ever more urgent. Until such a strategic approach is launched, initiatives to challenge climate impacts will be ad-hoc and stand-alone initiatives that leave building owners at a crossroads, uncertain of which climate impacts that are necessary to address and which scenarios have the most credibility.

Circumstances related to national and international policy, economics, energy use, emissions of greenhouse gases and the development of new energy-supply sources, demand a continued strategic approach to climate impacts and adaptation for existing buildings as well as building requirements.

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